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Single Tree Spray Systems

Progress Report

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5E52P64–Single Tree Spray Systems

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Introduction

The USDA Forest Service Missoula Technology and Development Center is helping the Pacific Southwest Research Station develop a sprinkler system for an individual tree. Forest health scientists were initially interested in this system for use with naturally occurring rust-resistant tree species. The single tree spray system was developed to protect tree cone crops from damage by cone and seed insects. The single-tree sprinkler system is intended for applying insecticide to the crown of a tree exhibiting superior blister rust resistance in a forest setting. The seeds produced by these genetically rust-resistant trees are highly valuable to reforestation.

In 1994, a second development effort was carried out with white pine trees at the tree improvement orchard at the Forest Service's Coeur d'Alene Nursery in Idaho. The purpose was to determine the system's effectiveness compared to the hydraulic sprayer system used now.

Single tree sprayer.

Initial Development

Initial development of the individual tree spray systems began in May of 1993. Research scientists at the U.S. Department of Agriculture Forest Service's Pacific Southwest Research Station (PSW) envisioned a spray system to apply a mixture of water and insecticide to the crown of an individual sugar pine tree located in a forest setting. The scientists wanted a spray system to control damage by the sugar pine cone beetle (*Conophthorus lambertianae* Hopkins) to second-year cones of naturally occurring rust-resistant sugar pine (*Pinus lambertiana* Dougl.).

The spray system envisioned would be used as follows. A certified insecticide applicator would drive a vehicle equipped with spray pump and mixing tanks to a tree in the forest. The applicator would connect a waterline from the spray pump to the waterline of the spray system near the base of the tree. After preparing the mixture, the applicator would operate the pump and spray the tree until runoff (when the crown is fully saturated and the mixture begins to run off). After the tree stopped dripping, the waterline would be disconnected at the base of the tree. The remaining water and insecticide mixture in the sprinkler system's waterline could be drained into a bucket and returned to the mixing reservoir.

Sprayhead

A typical pop-up style lawn sprinkler was selected for the sprayhead. When the sprinkler system is pressurized, the sprayhead's stem protrudes. When the water pressure is removed, spring tension retracts the stem into the sprayhead. Depending upon the nozzle used, retractable stems make it less likely the sprayhead will clog from dirt or insects. Several manufacturers make this type of sprinkler equipment. Because each manufacturer uses a different thread arrangement, components are generally not interchangeable between manufacturers. Rain Bird equipment was arbitrarily selected. It is readily available in most areas.

Nozzle

Each of the sprayheads was equipped with a Rain Bird 8F-FLT nozzle. This type of nozzle emits a spray in a 360° pattern at an angle of 5° with the horizontal plane. The spray pattern is 2.4 m (8 ft) in diameter at ground level when used for yard watering. This nozzle was selected because it emits a water spray at a much flatter angle than the standard nozzle (30°) or the low-angle nozzle (15°). The low trajectory of spray would be less affected by wind than the higher trajectory of spray. This nozzle is rated at 5.5 L/min (1.44 gpm) when operated at 138 kPa (20 psig).

Upper Section

The sprinkler was mounted to a 3-m (10-ft) length of 13-mm (1/2-in) Sch80 PVC pipe to keep it upright above the top of the tree. The 3-m (10-ft) section was created by joining 61-cm (2-ft) lengths. The 61-cm (2-ft) lengths would have been needed to install multiple nozzle configurations. A brass quick-connect coupling at the bottom end of the upper section allows more pipe sections to be added as the tree leader grows. The ability to detach the upper section from the waterline facilitates servicing the sprinkler. The rigid section also allows the sprinkler installer to secure the apparatus in the tree without having to go to the very top of the tree.

Waterline

Two types of waterline were selected to deliver water from the base of the tree to the bottom of the rigid PVC section of the spray system. High pressure synthetic fire hose was selected as one option for the waterline. This 5/8-inch hose has a woven synthetic jacket and is fully lined to prevent weeping. It has an operating pressure of 2068 kPa (300 psig). Standard 13-mm (1/2-in) polyethylene pipe was also selected for a waterline. This is the standard flexible pipe used in lawn irrigation systems and has an operating pressure of 1034 kPa (150 psig). The bottom end of each waterline had a 3/4-inch garden hose thread. A plastic cap installed on the bottom end of the waterline prevented insects from entering the line between applications. The flexibility of the lightweight firehose made it easy to install. However, the polyethylene pipe may be more resistant to damage from exposure to the elements and less susceptible to damage by animals.

Fluid Delivery System

The fluid delivery system consisted of a Hypro Series 7560 8-roller pump. This pump has a maximum flow capacity of 83 L/min (22 gpm) and can provide a maximum pressure of 2068 kPa (300 psi). A bypass was inserted downline of the pump to regulate the fluid pressure. A liquid-filled pressure gauge immediately downline of the bypass determined pressure at the pump outlet. A 3730 W (5.0 hp) Honda engine with a 6:1 gear ratio was selected for the power unit. A final belt drive of approximately 5:3 allowed the pump to be operated up to its maximum speed of 1000 rpm.

An 1140-L (300-gal) tank was used during the installation and spray drift tests. This tank was not practical for insecticide application because the mix tank needs to be triple rinsed after the application is complete. Before applying insecticide to the trees, the tank was replaced with a 114-L (30-gal) polyethylene tank for mixing and a 208-L (55-gal) tank for supply water.

Fiscal Year 1993 California Sugar Pine Study

Field Installation

Prototype spray systems were installed in three sugar pine trees on the Pineridge Ranger District of the Sierra National Forest near Shaver Lake, CA. One tree was previously certified as rust resistant. Two other trees were selected near the first tree to minimize travel time during installation, testing, and application. Maintaining the tree's health required special considerations when installing the spray system. To eliminate entry points for disease, the spray system was secured to the bole of the tree with 2.5-cm (1 in) nylon straps instead of nails, screws, or bolts. In addition, tree climbing ladders provided access to the crown of the tree, eliminating the use of climbing spurs. Plastic and brass components were used to minimize the possibility the spray system would become a lightning rod.

The spray crew decided the single sprinkler configura-tion had several advantages over a multiple sprinkler system. First, the single sprinkler configuration would be easier to install. In addition, it would be more likely to drain completely. The spray systems were intended to be permanent installations. During winter, any residual liquid remaining in a relative low point of the system would expand upon freezing, possibly damaging the system. Third, a single sprinkler configuration would not be as susceptible to breakage due to snow load or swaying of the tree branches. The system needed to be flexible enough to tolerate individual branches moving independently within the tree's crown.

Figure 1.–Tree climber Tim Veach installs the spray system in tree no. 1.

The first spray system was installed in a certified rust-resistant sugar pine (certification no. 1553-19225, Figure 1). It was 36 m (110 ft) tall with a deep crown. The tree was located by the roadside with the base at road level. The top of the spray system consisted of a single sprinkler head mounted on a section of rigid PVC pipe. Six 61-cm (2-ft) sections of 13-mm (1/2-in) PVC pipe were coupled together with the sprinkler mounted on one end. The pieces were assembled at ground level using Teflon tape as the thread sealant. A brass quick-disconnect fitting coupled the lower

end of the rigid PVC section to the 15-mm (5/8-inch) lightweight fire hose used from the end of the rigid portion to the ground (Figure 2). The materials for this spray system cost approximately $60 (Table 1).

The second spray system was installed in a sugar pine tree that was not rust resistant. This tree was 23 m (75 ft) tall. It had a full crown and a forked top. It was located about 45 m (147 ft) off the road. The base of the tree was approximately 6 m (20 ft) below road level. The spray system consisted of a single sprinkler head mounted on a 3-m (10-ft) rigid section similar to that installed in the first tree. Black, 13-mm (1/2-in) polyethylene pipe was used as the water line from the bottom of the rigid section down to the base of the tree (Figure 3). The materials for this spray system cost approximately $42 (Table 2).

The third spray system was installed in a sugar pine identified as a candidate for rust-resistant certification. The young, vigorously growing tree was 16 m (52 ft) tall with good form and branches nearly to the ground. It was about 60 m (200 ft) up the road from tree no. 1. Tree no. 3 was about 20 m (66 ft) from the road. Its base was approximately 3 m (10 ft) higher than the road. The spray system was similar to that installed in tree no. 2. (Drawings of the single tree spray systems are included in Appendix A.)

Figure 2.–Waterline used for single tree spray system in tree no. 1.

Figure 3.–Waterline used for single tree spray systems in sugar pines nos. 2 and 3.

Table 1.–Spray system material using lightweight fire hose.

Qty.	Part no.	Description	Price	Cost
1	RB8FFLT	8F-FLT nozzle		$0.84
1	RB1802	Rain Bird 2" pop-up spray sprinkler		$1.44
6	PN05240	Sch80 nipple 1/2X24"	$1.34	$8.04
5	P40CTT05	Sch40 coupling 1/2 TXT;	$0.27	$1.35
1		Quick connect coupling		$3.00
1	PIFA05	Fitting		$1.19
2	NFES #1016	Lightweight firehose 3/4 GHT	$15.92	$31.84
1		Fitting		$1.19
3	SSC05	Hose clamps	$0.36	$1.08
3	SSC20	Hose clamps	$0.39	$1.17
5		Straps	$1.50	$7.50
1	P450PT05	Plug		$1.19
				$59.83

Table 2.–Spray system materials using polyethylene pipe.

Qty.	Part no.	Description	Price	Cost
1	RB8FFLT	8F-FLT nozzle		$0.84
1	RB1802	Rain Bird 2" pop-up spray sprinkler		$1.44
5	PN05240	Sch80 nipple 1/2x24 long	$1.34	$6.70
4	P40CTT05	Sch40 coupling 1/2 TXT	$0.27	$1.08
1		Quick connect coupling		$3.00
1	PIFA05	Fitting		$1.19
3	SSC05	Hose clamps	$0.36	$1.08
3	SSC20	Hose clamps	$0.39	$1.17
10		Straps	$1.50	$15.00
1	PIFA05	Fitting		$1.19
AR	PP125051	Polyethylene pipe 1/2x100 NSF 340		$9.00
				$41.69

Field Testing

Testing was conducted to determine how effectively the system covered the tree crown, the spray conditions required to minimize drift, and the operating pressure required for coverage. The common spray droplet pattern assessment was used to verify coverage and detect drift. Rhodamine red dye, serving as the indicator, was added to the water in the spray tank. Kromekote drop cards were placed in the tree crown and on the ground to capture droplets. Certified tree climbers placed drop cards at three levels in the tree crown: level 1 was at the top of the cone-bearing portion of the crown, level 3 was at the bottom of the cone-bearing portion of the crown, and level 2 was midway between levels 1 and level 3. Drop cards were also placed on the ground at the dripline of the tree crown, 15 m (50 ft) from the base of the trunk, and 30 m (100 ft) from the base of the trunk. One dropcard was placed in each of the four cardinal directions at each of the three crown levels and each of the three distances from the trunk.

The approximate pressure needed to reach the top of a tree is about 28 to 35 kPa (4 to 5 psi) for every 3 m (10 ft) of difference in elevation between the water level in the spray tank and the top of the tree. In addition, about 103 to 207 kPa (15 to 30) psi is needed to operate the sprayhead. Table 3 shows the approximate pressure at the pump required to accommodate various elevation differences and pressure differentials across the sprayhead.

Table 3.–Pressure requirement for various elevation differences and sprayhead pressures.

Elevation difference		Sprayhead operating pressure					
		(20 psi)		(30 psi)		(40 psi)	
m	ft	kPa	psig	kPa	psig	kPa	psig
9.1	30	231	33.5	300	43.5	369	53.5
12.2	40	262	38.0	331	48.0	400	58.0
15.2	50	293	42.5	362	52.5	431	62.5
18.3	60	324	47.0	393	57.0	462	67.0
21.3	70	355	51.5	424	61.5	493	71.5
24.4	80	390	56.5	459	66.5	527	76.5
27.4	90	417	60.5	486	70.5	555	80.5
30.5	100	448	65.0	517	75.0	586	85.0
33.5	110	479	69.5	548	79.5	617	89.5
36.6	120	510	74.0	579	84.0	648	94.0
39.6	130	541	78.5	610	88.5	679	98.5
42.7	140	572	83.0	641	93.0	710	103.0
45.5	150	603	87.5	672	97.5	741	107.5

The first trial was conducted on tree no. 1. The pressure was set at 517 kPa (75 psig) just downstream of the pump bypass to obtain approximately 207 kPa (30 psig) drop across the nozzle. The Rain Bird specifications state (Appendix B) that for the 8F-FLT nozzle, a 207 kPa (30 psig) pressure drop produces 5.9 L/min (1.57 gpm) of spray. The sprinkler was operated for 10 min, producing a spray volume of roughly 57 L (15 gal). This trial was conducted at 2:30 p.m. on June 3, 1993. The afternoon wind was gusty, but the spray pattern looked very good when the wind was calm. The first test provided adequate coverage at crown level 1. Coverage at crown levels 2 and 3 was light. The northerly wind caused drift of numerous small droplets as indicated by the droplets on the ground level cards, 30 m (100 ft) from the base of the tree.

A second trial was conducted on tree no. 1. The pressure immediately downstream of the bypass was set to 414 kPa (60 psig) to obtain approximately 103 kPa (15 psig) pressure drop across the nozzle. Reducing the pressure across the nozzle results in larger water droplets. Larger water droplets would help compensate for gusty winds. The Rain Bird specifications state that for the 8F-FLT nozzle, a 103 kPa (15 psig) drop across the nozzle produces 4.4 L/min (1.16 gpm). The sprinkler was operated for 20 min, producing a spray volume of roughly 87 L (23 gal). This trial was conducted at 4:30 p.m. on June 3, 1993. Conditions were much windier than the previous trial. Drift was detected 30 m (100 ft) from the base of the tree. Testing was suspended until the next morning to minimize drift caused by the strong canyon updrafts that typically occur in the afternoon.

The first trial on June 4, 1993, was a repetition of the second trial conducted on tree no. 1 the day before. Drop cards were installed in tree no. 1 in the same manner as before. The pressure was adjusted to obtain 414 kPa (60 psig) immediately downstream of the bypass to obtain a 103 kPa (15 psi) pressure drop across the nozzle. The spraying was conducted for 20 min. About 95 L (25 gal) of water was sprayed under no wind conditions. During the test the pressure had crept up to 827 kPa (120 psig) for a brief period. The drop cards showed 100% coverage at level 1, approximately 50% coverage at level 2, and substantially less coverage at level 3. There were very few cones at crown level 3, so the coverage obtained was considered adequate. No drift was detected at 15 m (50 ft) or 30 m (100 ft).

Tree no. 2 was sprayed with a mixture of water and rhodamine dye. The spray pressure at the pump was 241 kPa (35 psig), which would yield 103 kPa (15 psi) at the nozzle. According to Rain Bird, specifications for the 8F-FLT nozzle, a 103 kPa (15 psi) drop across the nozzle produces 4.4 L/min (1.16 gpm) of spray. The sprinkler was operated for 20 min, producing a spray volume of roughly 87 L (23 gal). Wind speed was less than 2.2 m/s (5 mph). This trial was completed at 9:15 a.m. on June 4, 1993. The base of the tree was about 9 m (30 ft) below the elevation pump. Too

few drop cards were left, coverage was verified by visual inspection. Good coverage was obtained near the top of the crown and down to midcrown on the tree's lee side. The windward side received little coverage. Because the windward side of the tree had no cones, the sprinkler was not adjusted for future use. Tree no. 2 had a forked top. During installation, the sprinkler was secured to only one of the leaders, causing the sprinkler to be tilted slightly from vertical. The sprinkler leaned in the direction of the prevailing wind.

Tree no. 3 was sprayed with a mixture of water and rhodamine dye. The pressure at the pump was 276 kPa (40 psig) which would yield 103 kPa (15 psi) at the nozzle. According to Rain Bird, specifications for the 8F-FLT nozzle, a 103 kPa (15 psi) drop across the nozzle produces 4.4 L/min (1.16 gpm). The sprinkler was operated for 20 min, producing a spray volume of roughly 87 L (23 gal). The coverage on this tree was the most complete and uniform of any of the three trees. Tree no. 3 was not as tall as the surrounding trees and was protected from the wind, which was starting to pick up.

Insecticide was not applied because rain or snow was forecast for later on June 4, 1993. The rain would likely wash off the water and Asana XL insecticide mixture before it dried.

Pheromone insect traps were placed in three trees near the study area to monitor the stage of activity of the beetles. The contents of the traps were analyzed every 7 to 10 days to identify the insects (Figures 4 and 5).

For spray application, the 1140-L (300-gal) tank was impractical. The spray contracts specify that spray tanks must be rinsed three times. For containers with capacities over 18.9 L (5 gal), the volume of water required for each rinse is one-fifth the volume of the container. At the end of the application, the rinse water is supposed to be sprayed near the base of the project tree. It would be highly impractical to dispose of 681 L (180 gal) of rinse water in this manner.

The most spray required for any one tree was 95 L (25 gal). The 1140-L (300-gal) tank was replaced with a 114-L (30-gal) mix tank and a 208-L (55-gal) reserve tank. Good coverage with minimal drift was obtained by operating each spray system as indicated in Table 4.

Figure 4.–Carline Trummer installing pheromone trap.

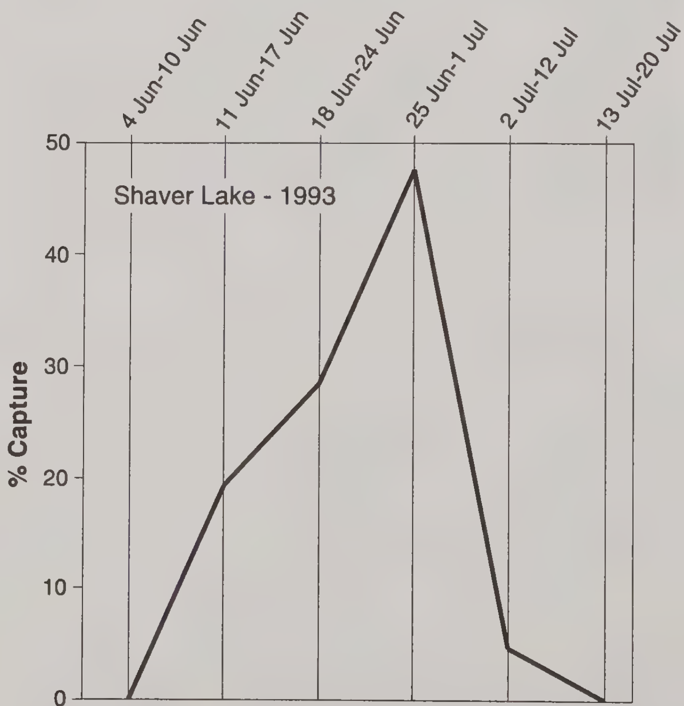


Figure 5.–Results of pheromone trapping of sugar pine cone beetles during the 1993 California sugar pine study. Jack Stein, Research Entomologist for the Pacific Southwest Research Station, prepared the figure.

Table 4.–Summary of pressures and durations during coverage and drift testing.

Tree no.	Pressure	Duration	Spray volume
1	414 kPa (60 psig)	20 min	95 L (25gal)
2	241 kPa (35 psig)	20 min	87 L (23 gal)
3	276 kPa (40 psig)	20 min	87 L (23 gal)

Insecticide Applications

The first application of insecticide using the single tree spray systems was applied on June 29, 1993. The research entomologist specified Asana XL for the insecticide. Because this insecticide is not currently registered for forest use, a special research application permit was obtained from the State of California Pesticide Regulatory Commission. The Asana XL was mixed into water at the manufacturer's recommended 75 mL/100 L (9.6 oz/100 gal). Rhodamine dye was added. Kromekote drop cards were placed at the dripline in the four cardinal directions to verify coverage. Additional drop cards were placed 30 m (100 ft) from the base of the tree in the four cardinal directions to determine spray drift. Tom Catchpole, certified insecticide applicator, performed the applications (Figure 6).

Figure 6.–Tom Catchpole, of the Sierra National Forest's Pineridge Ranger District, prepares insecticide mixture.

First Application

Tree no. 1 was sprayed at 7:30 a.m. under no wind conditions. The flow was adjusted to provide 414 kPa (60 psig) immediately downstream of the system bypass. A 95-L (25-gal) application was completed in 18 min. All drop cards at the dripline were covered with large drops. No drift was detected at 30 m (100 ft).

Tree no. 2 was sprayed under no wind conditions. All drop cards at the dripline were covered with standing pools of spray. No drift was detected at 30 m (100 ft). An estimated 38 to 57 L (10 to 15 gal) of spray was sufficient to provide complete coverage for a tree of this size.

When tree no. 3 was sprayed, a slight breeze blew from the west. The flow was adjusted to provide 276 kPa (40 psig) immediately downstream of the system bypass. An 87-L (23-gal) application was completed in 17 min. The west side of the tree crown received less coverage than the other three sides. Coverage on the west side was still considered adequate. Approximately 5 m (15 ft) of drift outside the dripline was detected on the east side. No drift was detected at 30 m (100 ft).

Spraying was completed at 9 a.m. The 114-L (30-gal) mix tank and the hoselines were triple rinsed. The rinse was deposited around the base of tree no. 1.

Second Application

The spray crew assembled at tree no. 1 on July 29, 1993, to repeat coverage and drift testing and apply Asana XL to the three sugar pine trees a second time. The crew connected the hoseline from the outlet of the fluid delivery unit to tree no. 1 and mixed 95 L (25 gal) of water with rhodamine dye. The engine on the pumping system was started and the flow adjusted to obtain a pressure of 414 kPa (60 psig) immediately downstream of the bypass. After about 20 s, the pump seized. The nylon coating on the pump's rollers had disintegrated. Nylon fragments caused the pump to seize. Spraying was suspended for the day while the pump was serviced. Drop cards were placed at the three levels in the crown of the tree in preparation for spraying the next day.

The rollers were replaced with Buna-covered rollers. In addition, the 19-mm (3/4-in) supply line from the mix tank to the pump inlet line was replaced with a 25-mm (1-in) supply line.

The spray crew reassembled at tree no. 1 on July 30, 1993, to try testing again. The crew connected the hoseline from the outlet of the fluid delivery unit to tree no. 1. The engine was started and the flow adjusted to obtain a pressure of 414 kPa (60 psig) immediately downstream of the bypass. Drop cards were placed at 15 m (50 ft) and 30 m (100 ft) from the base of the tree in the four cardinal directions. Approximately 95 L (25 gal) of rhodamine-dyed water was applied to the tree. Good coverage was obtained at all levels of the crown. No drift was detected at 15 m (50 ft) and 30 m (100 ft).

The truck was moved and the hoseline was connected to tree no. 3. The flow was adjusted to obtain a pressure of 276 kPa (40 psig) immediately downstream of the bypass. Approximately 57 L (15 gal) of dyed water was applied. The drop cards were replaced in tree no. 3 and the coverage and drift tests were repeated. Both tests provided good results with full coverage at all levels of the crown. No drift was detected.

With the coverage and drift testing completed, a second insecticide application was prepared for tree no. 1. The research entomologist decided not to apply Asana XL to trees nos. 2 and 3. Tree no. 2 was not rust resistant and tree no. 3 no longer had any cones.

The second application of insecticide was applied to tree no. 1 on July 30, 1993. A 95-L (25-gal) mixture of water and Asana XL was prepared according to the manufacturer's recommended 75 mL/100 L (9.6 oz/100 gal). Rhodamine dye was added to the mixture as a visual indicator. Kromekote drop cards were placed at the dripline in the four cardinal directions to verify coverage. Drop cards were placed 30 m (100 ft) from the base of the tree in the four cardinal directions to determine spray drift. Tom Catchpole, a certified insecticide applicator, applied the insecticide. The flow was adjusted to provide 414 kPa (60 psig) immediately downstream of the system bypass. A 95-L (25-gal) application was completed in 18 min. All drop cards at the dripline were covered with large drops. No drift was detected at 30 m (100 ft).

Cone Harvest

In September of 1993, Tom Catchpole used a .22-cal. rifle to harvest approximately half a bushel of cones from tree no. 1. Because of the limited number of installations and the minimal cone crop in 1993, the efficacy of the single tree spray system could not be determined.

Orchard Study

In May of 1994, the efficacy of the single tree spray system was studied at the Forest Service's Coeur d'Alene Nursery seed orchard in Idaho. The study was a cooperative effort involving the USDA Forest Service's Northern Region (Region One), MTDC, and the Coeur d'Alene Nursery. Northern Region entomologists wanted to determine if the single tree spray system could control insect damage to cones of the western white pine (*Pinus monticola* Dougl. ex D. Don) primarily due to the western conifer seed bugs (*Leptoglossus occidentalis* Heidemann). Coneworms (*Dioryctria abietivorella* Grote) and cone beetles (*Conopthorus ponderosae* Hopkins) have been found in the orchard, but are much less prevalent.

Thirty trees, each bearing more than 75 cones, were selected. Ten trees received an insecticide application using single tree spray systems. Another 10 trees were treated using the hydraulic sprayer, the standard application practice in the seed orchard. Another 10 trees serving as control trees, were not treated with insecticide. The trees received their designation by lot. A map indicating which seed orchard trees were involved in the study is included in Appendix C.

Before insect emergence in the spring, 10 cones on each of the 10 control trees were bagged to eliminate exposure to insects. In addition, 10 unprotected cones were randomly collected from each control tree during harvest. Analysis of the bagged cones and the cones exposed to the insect infestation would indicate the maximum seed loss.

The nursery uses an FMC Bean sprayer in standard practice to apply insecticide to the trees in the seed orchard. The sprayer is pulled with a tractor between the seed orchard rows. Two persons sit on a platform at the rear of the sprayer. They apply the insecticide and water mixture using spray guns. The Bean sprayer (Model No. D010E200S) has a capacity of 37.9 L/min (10 gpm) and 3450 kPa (500 psig).

The two Rain Bird nozzles being considered for this application required less than 7.6 L/min (2 gpm) and 276 kPa (40 psig) to operate, according to the manufacturer's specifications. Since the Bean sprayer could meet these requirements, it was adapted for the single tree spray systems. This eliminated the need to design a fluid delivery system just for this study. The Bean sprayer hose was fitted with a garden hose coupling to connect the spray hose and the sprinkler system at the base of the tree.

Installation

On May 11, 1994, a Northern Region entomologist, Nursery personnel, and Missoula Technology and Development Center staff (Appendix D) installed sprinklers in the 10 study trees. The orchard was established in 1972 with 2-year-old western white pine seedlings. The seedlings were planted on a 6-m (20-ft) spacing in rows 6 m (20 ft) apart. The tops of the trees are pruned every 3 to 5 years to keep the tree height between 8 and 10 m (25 to 30 ft). A hydraulic, telescoping lift provided easy access to the tree tops to install the spray systems.

A standard Rain Bird 3-inch pop-up spray sprinkler was used as the sprayhead. Due to the shape of the tree crown and the height of the tree, it was not necessary to use a 10-ft rigid section of PVC pipe at the top of the sprinkler system. The sprinkler was mounted directly on the 13-mm (1/2-in) black polyethylene sprinkler pipe. Nylon cord secured the spray system to the bole of the tree. The pipe was cut long enough to extend beyond the canopy at the ground. This would allow the applicator to drain and disconnect the spray system without waiting for the tree to stop dripping. Materials for each spray system cost about $10 (Table 5).

Table 5.–Spray system materials used in the seed orchard study.

Qty.	Part no.	Description	Price	Cost
1	RBSX360	Nozzle		$0.72
1	RBXBA1800	Nozzle adapter		$0.56
1	RB1802	Rain Bird 2" pop-up spray sprinkler		$1.44
1	PIFA05	Fitting		$1.19
	PP125051	Polyethylene pipe; 125#1/2X100 NSF 340		$3.00
1		Fitting		$1.19
2	SSC05	Hose clamps	$0.36	$0.72
		Brass cap 3/4 GHT		$0.59
				$9.41

Testing

On May 11, 1994, the spray crew conducted two tests each on three trees. The spray tests were conducted with a mixture of water and rhodamine dye. Spray deposit cards were placed in the four cardinal directions near the top of the crown and about 40% of the way from the top to the bottom of the crown. One card was placed at this level in the crown of each of the four adjacent trees. Drop cards were placed in the four cardinal directions at the drip line.

Drop cards were placed 6 m (20 ft) from the base of the tree in the northeast, northwest, southeast, and southwest directions. During the final test, drop cards were also placed 15 m (50 ft) from the base of the tree in the northeast, northwest, southeast, and southwest directions to measure drift (Figure 7).

Figure 7.–Spray deposit cards installed in a western white pine during field testing of single tree spray systems at Coeur d'Alene seed orchard.

The first nozzle used was the Rain Bird 8F-FLT (Figure 8), the same nozzle used in the sugar pine spray systems in 1993. This nozzle sprays in a 360° pattern at an angle of 5° above horizontal. The second nozzle tested was the Rain Bird XS-360 adjustable radius sprayer (Figure 9, Appendix B). This unit, typically used in drip irrigation systems, requires an adapter for use with the pop-up lawn sprinkler. It sprays in a 360° pattern and has an adjustment to change the spray. All the XS-360 nozzles were installed with the arrowhead on the adjustment knob oriented at 90° to and pointing away from the flat, top surface of the sprayhead. For the single tree spray system application, the spray radius will be controlled by varying the operating pressure on the FMC Bean sprayer. In addition to the differing spray patterns, the flow rate through the 8F-FLT nozzle is approximately three times the flow rate through the XS-360 at the same pressure.

Figure 8.–Testing the Rain Bird 8F-FLT nozzle at the Coeur d'Alene Seed Orchard.

Figure 9.–Testing the Rain Bird XS-360 variable spray nozzle at the Coeur d'Alene Seed Orchard.

Tree no. 23 (Trial no. 1)—The tree was sprayed for approximately 3 min at 207 kPa (50 psig), using a Rain Bird 8F-FLT nozzle when the wind was 2.2 m/s (5 mph) from the northeast. The top of the tree received complete coverage. The midlevel received good coverage on the west and south, but little or no coverage on the north and east. There was heavy drift on the south and some drift on the west on the adjacent trees. The dripline was heavy on the southwest, with 20 to 30% coverage on the northwest and southeast and none on the northeast. The drift, measured at the 6 m (20 ft), was fine drops with heavy coverage on the southwest.

Tree no. 21 (Trial no. 1)—The tree was sprayed for approximately 2-1/2 min at 207 kPa (50 psig) and for 1 min at 207 kPa (30 psig), using the Rain Bird 8F-FLT nozzle. There was a steady 2.2 m/s (5 mph) wind from the south. The top of the tree was completely covered. Coverage on the midlevel was complete, except on the south, which had less than 5% coverage. Adjacent trees received 10% coverage on the east and none on the south. The dripline was complete on the north, with 75% coverage on the east and the west and several drops on the south. At the 6-m (20-ft) line there was no drift toward the southwest or southeast. There was 40% fine drops and medium coverage on the dropcard detecting drift to the northeast.

Tree no. 23 (Trial no. 2)—The tree was sprayed using a Rain Bird XS-360 adjustable radius sprayer nozzle for approximately 3-1/2 min at 207 kPa (30 psig). Wind was from the southwest, steady at 2.2 m/s (5 mph). Coverage was good at the top. Coverage at the midlevel was good on the north and east, with 10% coverage on the south and 5% coverage on the west. Coverage on the adjacent trees was complete on the east, with 20% coverage on the north. Coverage on the dripline was 30% on the northeast and southeast, 10% on the northwest, and less than 5% on the southwest. At the 6-m (20-ft) line, coverage was complete on the northeast, none on the southwest, and less than 5% on the northwest and southeast.

Tree no. 21 (Trial no. 2)—The tree was sprayed using a Rain Bird XS-360 adjustable radius sprayer nozzle for approximately 4 min at 152 kPa (22 psig). The wind was gusting from the south at 2.2 to 4.4 m/s (5 to 10 mph). Coverage at the top was complete. Coverage at midlevel was 80%. Adjacent trees received 20% coverage on the east and 30% coverage on the south. The dripline received 15% coverage on the west, 20 to 25% coverage on the north, less than 5% coverage on the east, and less than 1% coverage on the south. Drift at the 6-m (20-ft) line was none on southeast, one drop on the southwest, large drops and 30% coverage on the northwest, and large drops and 20% coverage on the northeast.

Tree no. 24 (Trial no. 1)—The tree was sprayed using a Rain Bird XS-360 adjustable radius sprayer nozzle for approximately 3-1/2 min at 207 kPa (30 psig). The only wind was an occasional gust from 2.2 to 4.4 m/s (5 to 10 mph) from the south. Coverage at the top was

marginally good, with medium drops and 40% coverage on the north, south and east, with large drops and 95% coverage on the west. The midlevel received 50 to 60 drops on the east and north, 10% coverage on the south, and 50% coverage on the west. Adjacent trees received 70% coverage on the north, 30% coverage on the west, and 20% coverage on the east. The dripline had three drops on the south, 10% coverage on the west, 20% coverage on the east, and 30 to 40% coverage on the north. The drift at the 6-m (20-ft) line was none on the southeast and southwest, 10% coverage on the northeast, and 40% coverage on the northwest.

Tree no. 24 (Trial no. 2)—The tree was sprayed using a Rain Bird XS-360 adjustable radius sprayer nozzle for approximately 3-1/2 min at 152 kPa (22 psig) when the wind was a steady 4.4 m/s (10 mph) from the south. Coverage at the top was complete. Midlevel coverage was complete on the east and north, with 15 to 20% coverage on the south and west. Adjacent trees received complete coverage on the north, 10% on the east, and less than 5% on the west. The dripline had 90% coverage on the east and north, 25% coverage on the south, and 10% coverage on the west. Drift at the 6-m (20-ft) line was 10% coverage on the northwest, and 5% coverage on the northeast. No drift was detected toward the southeast and southwest. No drift was detected 15 m (50 ft) from the base of the tree.

Spray applications began at 8:15 a.m. and ended at 12:05 p.m.

Due to the unpredictability of insect flight, the Northern Region entomologist wanted to have the spray systems installed and operational by mid-May. Insect populations could be monitored regularly to determine the appropriate time to apply the spray.

The amount of spray applied per tree during the trials was approximately 5.7 L (1.5 gal). The trial tests were conducted at 207 kPa (30 psig) for 3.5 min.

Wind speeds were approximately 4.5 to 7 m/s (10 to 15 mph) during the test. Although that would not be acceptable for an application, it provided a worst-case test of the spray system.

From a qualitative analysis of the drop cards, the XS-360 nozzle performed the best in minimizing drift. The wind had a greater effect on the spray from the 8F-FLT nozzle. There didn't appear to be much difference in the coverage. Therefore, an XS-360 nozzle was installed in the sprayhead of each single tree spray system.

Insecticide Applications

Insecticide application in the seed orchard was postponed until July. The Pounce manufacturer recommends this product not be applied until 30 days after the cone flowers have blossomed otherwise the tree may abort the cones.

The insecticide applications began on July 11, 1994. A mixture of 177 mL (6 oz) Pounce and 379 L (100 gal) of water was prepared in the sprayer. Although this mixture is half the ratio recommended by the manufacturer, this is the nursery's standard ratio for hydraulic spraying. Seedbugs are extremely susceptible to the insecticide.

For each application, drop cards were placed at the dripline in the four cardinal directions to verify coverage. To detect drift, drop cards were placed at 15 m (50 ft) from the bole of the tree in the northeast, southeast, southwest, and northwest directions.

Tree no. 2—The tree was sprayed for 5 min at 207 kPa (30 psig) at the pressure gauge. The leader of the tree had grown above the top of the sprinkler on the southeast side. This altered the spray pattern there. In addition, the application was conducted during a 1.3m/s (3 mph) wind from the southeast direction. Consequently, no coverage was obtained on the southeast side of the tree. Very good coverage was obtained on the northwest side.

The radius of the spray pattern may have been too large to provide uniform coverage at the top of the crown. The spray crew decided to spray the rest of the trees at approximately 207 kPa (30 psig) for 3 min and 172 kPa (25 psig) for 3 min.

Tree no. 19—The tree was sprayed for approximately 5 min at 207 kPa (30 psig) and 3 min at 172 kPa (25 psig). Wind speeds on the ground were approximately 2.2 m/s (5 mph) from the southeast direction. Good coverage was obtained on all sides of the tree.

Tree no. 6—The tree was sprayed for approximately 3 min at 241 to 276 kPa (35 to 40 psig) and 3 min at 172 to 207 kPa (25 to 30 psig). The air was calm except for an occasional 1.3 m/s (3 mph) wind gust from the southeast. Good coverage was obtained on all sides of the tree.

Tree no. 18—The tree was sprayed for approximately 3 min at 276 kPa (40 psig) and 3 min at 172 to 207 kPa (25 to 30 psig). The air was calm except for an occasional 1.3- to 2.2-m/s (3- to 5-mph) wind gust from the southeast. Good coverage was obtained on all sides of the tree.

Tree no. 17—The tree was sprayed for approximately 3 min at 276 kPa (40 psig) and 4 min at 228 kPa (33 psig). Wind speeds on the ground were approximately 2.2 m/s (5 mph), gusting to 2.2 to 4.4m/s (5 to 10 mph) from the southeast direction. Coverage was heavy on the north and west cards at the dripline. No coverage was obtained on the south side of the tree. Drift was present on the northeast. Some drift from application to no. 17 was detected on the southeast and southwest drop cards placed for drift measurement for testing no. 18.

Spray applications began at 7:45 a.m. and were suspended at 9:20 a.m. due to the wind conditions.

The amount of spray applied to each tree was approximated from the pressure settings, times, and manufacturer's data on the XS-360 nozzle. These approximations are shown in Table 6.

Table 6.–Summary of spray volumes applied July 11, 1994.

Tree no.	Spray volume
2	7.6 L (2.0 gal)
19	11.7 L (3.1 gal)
6	9.5 L (2.5 gal)
18	9.8 L (2.6 gal)
17	12.1 L (3.2 gal)

Coverage at the dripline was very even and complete for all applications except tree no. 2 and tree no. 17. The south side of tree no. 2 received no coverage. No coverage was detected on the south side at the dripline due to strengthening winds. Coverage on the north side was heavier as a result. The drops on the north side were much finer than those obtained during the other applications. The reduced coverage was probably due to the leader growth above the sprinkler and the wind direction. The finer drops were probably due to higher pressure.

On Tuesday, July 12, 1994, a two-person spray crew completed the sprinkler application on the remaining five trees. All applications were made at 241 kPa (35 psig) for 3 min and 172 kPa (25 psig) for 3 min. About 10.2 L (2.7 gal) of insecticide was applied per tree. Spray and drift were monitored at the dripline and 15 m (50 ft) from the bole of the tree in the same manner as spray and drift were monitored the previous day.

Tree no. 24—The tree was sprayed during steady wind conditions of 2.2 m/s (5 mph) from the southeast. Good coverage was obtained on the north and west. Moderate coverage was obtained on the southeast. No drift was detected.

Tree no. 23—The tree was sprayed during steady wind conditions of 2.2 m/s (5 mph) from the southeast. There was excellent coverage on the north, south, and west. Moderate coverage was obtained on the east. No drift was detected.

Tree no. 21—The tree was sprayed during steady wind conditions of 2.2 m/s (5 mph) from the south/southeast. Coverage on the north and west was excellent. Little coverage was obtained on the south and east. No drift was detected.

Tree no. 13—The tree was sprayed during steady wind conditions of 2.2 m/s (5 mph) with direction varying from the east, southeast, and southwest. Coverage was excellent on all drop cards. No drift was detected.

Tree no. 29—The tree was sprayed when the wind was 2.2 m/s (5 mph) from the east/southeast. Coverage was excellent all around. No drift was detected.

The amount of spray applied to each tree was approximated from the pressure settings, times, and manufacturer's data on the XS-360 nozzle. All trees (nos. 24, 23, 21, 13, and 29) received about 8.7 L (2.3 gal) of spray.

The nursery performed the hydraulic application of Pounce insecticide to the remainder of the seed orchard trees on July 14 and 15, 1994. According to nursery records, approximately 1195 trees were sprayed using 3030 L (800 gal) of water and insecticide mixture. The mixture was prepared using of 47 mL Pounce per 100 L water (6 oz Pounce per 100 gal water). A total of 1420 mL (48 oz) of Pounce was used during the hydraulic sprayer application.

California Sugar Pine Study

In early June, the three sugar pine tree systems were tested with water to determine if they were functional. A year after being installed, only two of the three spray systems in sugar pine trees in California were still functional. The spray system installed in sugar pine no. 2 failed when the system was pressurized. Water sprayed out the side of the sprayhead. A binocular inspection revealed a vertical crack on the side of the sprayhead. The center did not have time to investigate the cause of failure. Tom Catchpole, forester for the Pineridge Ranger District conducted three applications of Asana XL during the summer of 1994.

First Application

The first insecticide applications were performed on June 15, 1994. Asana XL was mixed into water at the manufacturer's recommended 75 mL/100 L (9.6 oz/100 gal). Three applications to tree no. 1 were conducted between 7:30 and 8:30 a.m. The 246 L (65 gal) applied covered approximately two-thirds of the crown of the 35-m (115-ft), rust-resistant sugar pine. Throughout the application, the operating pressure was varied between 345 and 483 kPa (50 to 70 psig) to minimize drift due to the varying wind conditions. The nozzle appeared to be partially clogged, reducing the 360° spray pattern.

Minimal drift indicated by a few small drops was detected 30 m (100 ft) from the base of the tree. Slightly more was detected at 15 m (50 ft). The drop cards at the dripline indicated coverage on the east, south and west sides of the tree. A visual inspection using binoculars indicated good coverage in the upper two-thirds of the crown on the southwest and northwest sides. Fair coverage was obtained on the southeast side. Poor coverage was obtained on the northeast side. A visual inspection using binoculars indicated this tree had an estimated 120 cones in good condition.

An insecticide application to tree No. 3 was conducted between 8:35 and 9:00 a.m. The 95-L (25-gal) application covered approximately two-thirds of the crown of the 16-m (52-ft) sugar pine, a rust-resistant candidate. Throughout the application, the operating pressure was varied between 248 and 276 kPa (36 to 40 psig) to minimize drift due to the varying wind conditions.

No drift was detected 30 m (100 ft) from the base of the tree. Minimal drift was detected at 15 (50 ft). Complete coverage was obtained on all sides of the tree. This tree had about 15 to 20 good cones.

Second Application

The second insecticide applications were performed on July 13, 1994. Asana XL was mixed into water at the manufacturer's recommended 75 mL/100 L (9.6 oz/100 gal). About 114 L (30 gal) was applied to tree no. 1 between 6:50 and 7:15 a.m. The wind was a steady 0.9m/s (2 mph) from the northeast, measured on the ground. Throughout the application, the operating pressure was varied between 345 and 483 kPa (50 to 70 psig) to minimize drift. After waiting for wind gusts to diminish, another 95 L (25 gal) of mixture was applied between 7:55 and 8:10 a.m.

No drift was detected 30 m (100 ft) from the base of the tree. A visual inspection through binoculars indicated three-fourths of the cones received coverage. In addition, approximately 20% of the cones showed indications of insect attack.

Insecticide was applied to tree no. 3 between 8:35 and 9:00 a.m. The 95-L (25-gal) application covered approximately two-thirds of the crown of the 16-m (52-ft) sugar pine, a rust-resistant candidate. Throughout the application, the operating pressure was varied between 248 and 276 kPa (36 to 40 psig) to minimize drift due to the varying wind conditions.

No drift was detected 30 m (100 ft) from the base of the tree. Minimal drift was detected at 15 m (50 ft). Complete coverage was obtained on all sides. The applicator noted most of the cones were aborted and nearly all of the cones appeared to be attacked by cone beetles. The application was completed to verify the coverage and capabilities of the system.

Third Application

A third insecticide application to tree no. 1 was performed August 4, 1994. Asana XL was mixed into water at the manufacturer's recommended 75 mL/100 L (9.6 oz/100 gal). The application to tree no. 1 began at noon. The windspeed measured on the ground was a steady 2.2 m/s (5 mph) from the east. The operating pressure during the 114-L (30-gal) application was mostly between 345 and 483 kPa (50 to 70 psig). Occasionally, the operating pressure was lowered to 317 kPa (46 psig) to minimize drift due to the wind gusts.

No drift was detected 30 m (100 ft) from the base of the tree. A visual inspection with binoculars indicated coverage was obtained on the east side of the tree only. About half of the cones received coverage.

Tree no. 3 was not sprayed because no healthy cones were on the tree.

Cone Harvest

Circumstances in autumn 1994 did not allow cones to be harvested from the three California sugar pine trees equipped with single tree spray systems. About 60 to 70 healthy cones matured on the rust-resistant sugar pine tree (no. 1). Cone harvesters arrived at tree no. 1 on September 17, 1994. The cones had already opened allowing the wind to disperse the seeds. Apparently, this tree opens its cones about 3 days earlier than the rest of the sugar pines at that elevation.

Fiscal Year 1994 Results

Single Tree Spray Systems Applications

The results of the five single tree spray system applications performed on July 11, 1994 are summarized here in Table 7.

Table 7.–Results of single tree spray system insecticide applications: July 11, 1994.

No.	Wind	Pressure	Time	Volume
2	<1.3 m/s(3 mph); southeast	207 kPa (30 psig)	5 min	7.6 L (2.0 gal)
19	2.2 m/s(5 mph); southeast	207 kPa (30 psig) 172 kPa (25 psig)	5 min 3 min	11.7 L (3.1 gal)
6	occasional 1.3 m/s(3 mph) gusts; southeast	262 kPa (38 psig) 193 kPa (28 psig)	3 min 3 min	9.5 L (2.5 gal)
18	1.3-2.2 m/s(3-5 mph) gusts; southeast	276 kPa (40 psig) 193 kPa (28 psig)	3 min 3 min	9.8 L (2.6 gal)
17	steady 2.2 m/s(5 mph) with occasional gust to 4.4 m/s(10 mph); southeast	276 kPa (40 psig) 228 kPa (33 psig)	3 min 4 min	12.1 L (3.2 gal)

The remaining five single tree spray system applications (trees nos. 24, 23, 21, 13, and 29) were completed July 12, 1994. All trees received about 8.7 L (2.3 gal) of spray applied at 241 kPa (35 psig) for 3 min and at 172 kPa (25 psig) for another 3 min. The wind was steady at 2.2 m/s (5 mph) from the south to southeast. No drift was detected.

Hydraulic Sprayer Applications

The remaining 1195 seed orchard trees were sprayed on July 14 and 15, 1994. Nursery personnel performed the hydraulic applications using the same mixture used in the single tree spray systems. A total of 3030 L (800 gal) of insecticide solution (Pounce) was applied.

Cone Analysis

In August of 1994, cones were harvested from the 30 trees involved in the study. Ten cones were randomly selected from each of the 10 trees treated with the hydraulic sprayer and from each of the 10 trees treated with the single tree spray systems. In addition to the 10 cones randomly selected from each of the 10 control trees, the 10 cones covered with bags on each of the control trees were harvested. After pollination in the spring, these cones had been bagged to prevent insect attack during the study.

The purpose of the seed orchard is to provide blister rust-resistant white pine seed for the Northern Region's reforestation program. Insecticides are used in seed orchards to reduce insect attack on the cones. When seed bugs feed, they leave partially filled or empty seeds that do not germinate. A cone analysis determined the number of viable, healthy seeds produced.

Preliminary results indicate the single tree spray systems provided greater seed protection than the hydraulic sprayer. Northern Region Insect and Disease Management will publish the final results later this year.

Sugar Pine Study

Three insecticide applications were performed on tree no. 1 during the summer of 1994. At the first application, the tree had approximately 120 healthy cones. About 60 to 70 cones (50 to 58%) reached maturity. The reforestation forester noted this was the most healthy cones produced by this particular tree in the 5 or 6 years since it was certified rust resistant. In past years, the tree aborted all or nearly all cones due to insect damage.

Discussion

During 1994, about 50 to 60% of the cone crop of the sugar pine tree no. 1 reached maturity. From the District's past experience, only about 5 to 10% of the sugar pine cones typically mature. Based on the number of cones that reached maturity, insecticide applied with a single tree spray system may increase cone crop yield fivefold. Because the cones opened early, a cone analysis could not be performed to determine the yield of healthy, viable seeds.

Further investigation is required to determine the durability of single tree spray systems in natural forest settings. After 1 year, only two of the three spray systems installed in California were still functional. Preliminary evidence in the spring of 1994 indicates one system failed because of problems in the sprayhead. Further investigation is planned for the summer of 1995. At that time, the two functional single tree spray systems will be retested to determine if they are still functional.

During the testing of single tree spray systems at the Coeur d'Alene Nursery, adequate coverage was obtained when the wind speed was below 4.4 m/s (10 mph). However, when the wind speed was higher than 2.2 m/s (5 mph), drift was excessive.

Pineridge Ranger District personnel suggested exploring the concept of a spray system that could be transported by snowmobile. Sometimes accessibility is marginal when insect activity begins. A spray system transported by snowmobile would allow access in early spring to ensure the application is conducted before the insects' flight season.

Another concept that could be explored is a spray system transported by helicopter. A helicopter would greatly reduce the travel time between trees located throughout the forest. This would allow many trees to be sprayed in a short time. A cost analysis would be needed to determine the number of genetically superior trees required to make this concept cost effective.

Preliminary results of the cone analyses from the seed orchard study indicate the single tree spray systems provided greater seed protection than the hydraulic sprayer technique. Insect damage on cones from trees with the individual tree sprinklers more closely resembled insect damage on the bagged control cones. Insect damage on cones from trees sprayed with the hydraulic sprayer resembled damage on the control exposed cones.

The greater efficacy of the single tree spray systems in the seed orchard study is probably due to two primary reasons:

- More insecticide was applied to each tree crown with the single tree spray systems. One insecticide application of 7.6 to 12.1 L (2.0 to 3.2 gal) of mixture per tree was applied with the single tree spray systems. The hydraulic sprayer was used to apply 3028 L (800 gal) of mixture to approximately 1200 trees. This results in about 2.5 L (0.7 gal) of mixture per tree. The nursery had planned a second application of insecticide using the hydraulic sprayer. It could not be scheduled early enough to minimize insecticide residue on the cones when they were harvested.

- Better coverage was obtained at the top of the tree with the single tree spray system than with the hydraulic sprayer. The hydraulic spray system used at the nursery was capable of applying insecticide to a height of 8 m (25 ft). The trees in the seed orchard were 8 to 10 m (25 to 30 ft) tall. The upper portion of the tree crown typically produces more cones.

The single tree spray system is more labor intensive than the hydraulic sprayer. In two 6-hour days, three people performed the hydraulic spray applications on approximately 1200 seed orchard trees. In two 2-hour days, two people performed the single tree spray system applications on 10 trees.

Installing single tree spray systems throughout the Coeur d'Alene Nursery seed orchard would require greater capital investment than the hydraulic sprayer. The cost of materials for installing a single tree spray system is about $10 per tree. By comparison, the hydraulic sprayer's replacement cost is around $5,000.

For seed orchard applications, the emphasis could be on improving the capabilities of the hydraulic sprayer. The hydraulic spray application technique should be modified to obtain greater volume of application per tree and better coverage throughout the tree crown. Improving these capabilities without compromising production and drift control would make this system invaluable for controlling insect damage in seed orchards. The Coeur d'Alene Nursery has begun developing an improved spray system consisting of a sprayhead mounted on a telescoping radio tower.

Another suggestion for seed orchard applications is the use of a rotary atomizer mounted on the back of a spray rig. This technique is commonly used in commercial fruit and nut orchards. The mounting system may need to be modified to accommodate taller trees typically found in Forest Service seed orchards. The system should be designed to minimize drift. Performance parameters for drift control would have to be stringent for this system to be practical where drift is not allowable.

Conclusions

At present, the single tree spray systems are a good alternative for applying insecticide to trees in the natural forest setting. These systems can be adapted to a wide range of field conditions. Tree height, the location of the tree in relation to the road, and the size and shape of the tree crown are conditions that can be accommodated by the single tree spray system. The materials for the single tree spray systems installed in rust-resistant sugar pines in their natural forest settings cost from $40 to $60 per installation.

There are some limitations for using single tree spray systems in a natural forest setting. Planning is required to allow the necessary time for submitting environmental documentation and obtaining insecticide application permits. Before insecticide is sprayed in the National Forests, documentation is required to meet EPA regulations. In addition, State and County permits may have to be obtained.

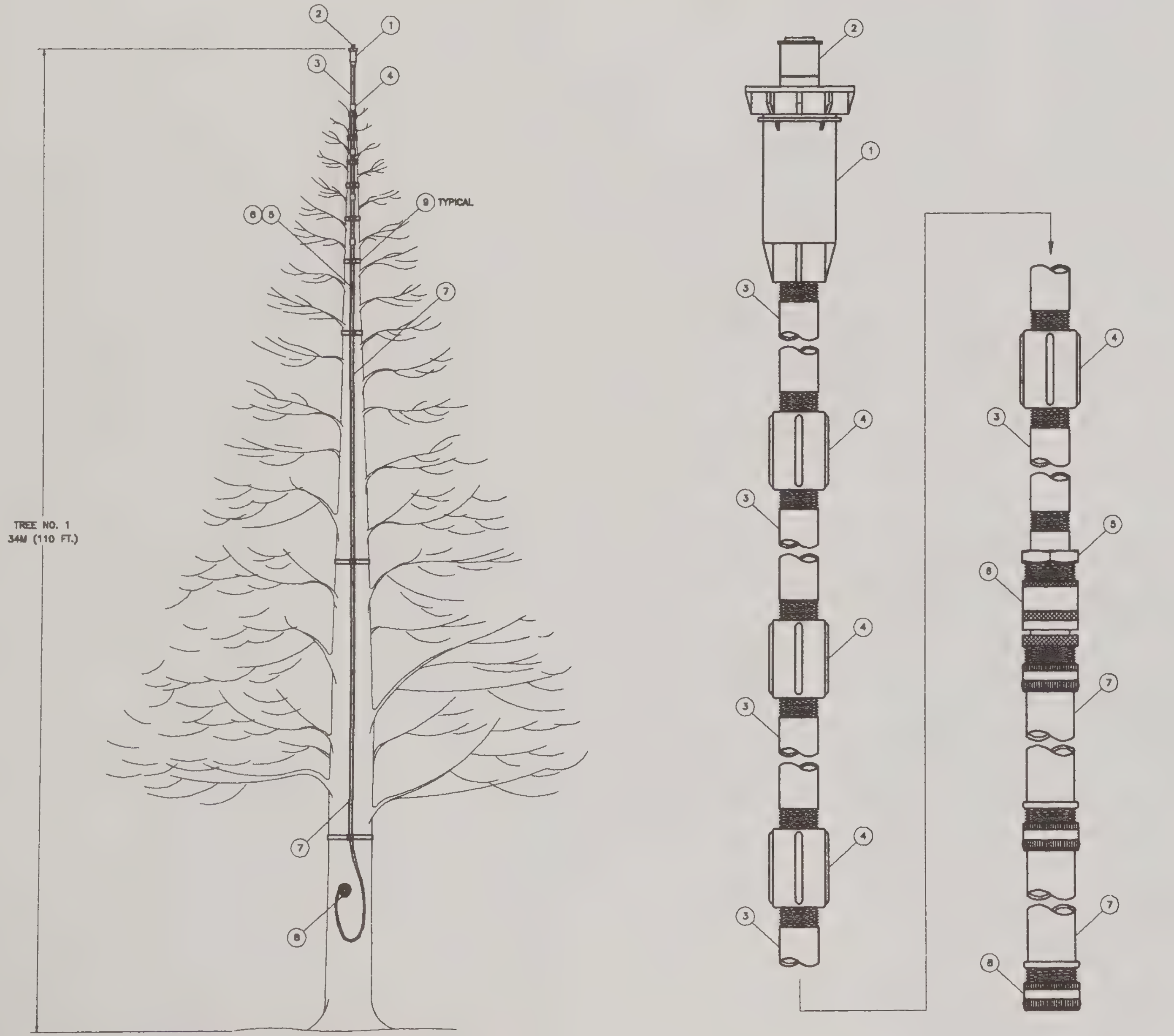
Genetically superior trees occur randomly throughout the forest. The amount of travel time required to service these trees limits the number of trees that can be sprayed during the effective application window.

Weather plays an important limiting role. In order to control drift, the insecticide must be applied when the wind speed is low, or ideally, during no wind conditions. It is also essential to apply the first insecticide treatment during the early spring before insect flight is expected to begin. Trees need to be accessible before insect flight, even during winters with above-average snowfall.

In nurseries, single tree spray systems also have some merit. Because crown coverage was more thorough, and because more mixture was applied per tree, single tree spray systems were more effective at controlling seed damage due to seed bugs than the hydraulic sprayer used at the Coeur d'Alene Seed Orchard.

Single tree spray systems also have limitations in nurseries. Materials for temporary single tree spray systems at the Coeur d'Alene Seed Orchard study cost about $10 per installation. Materials cost for permanent installations will be higher. This does not include the cost of labor for the installation. The time required to apply insecticide is another limitation. Since the application takes longer, operating costs for labor are much higher per tree than costs associated with the hydraulic spray system. In addition, the amount of time needed per tree will limit the number of trees that can be sprayed during the effective application window.

Appendix A—Single Tree Spray System Drawings



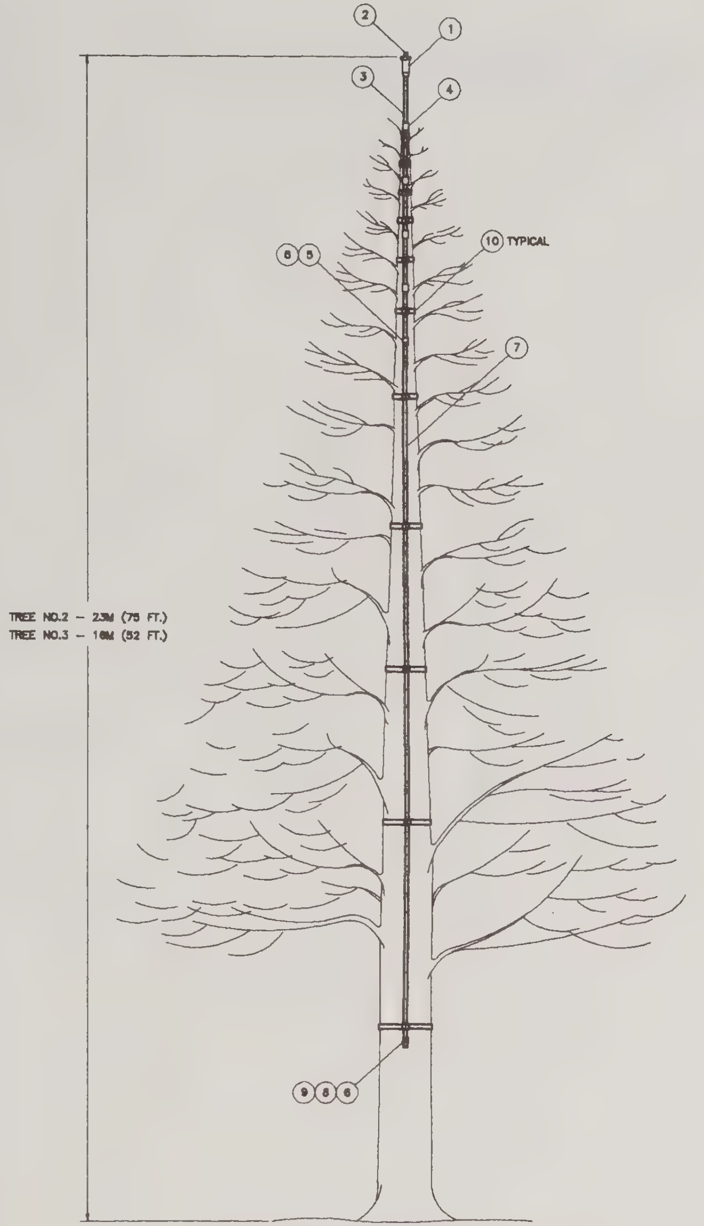
ASSEMBLY – CALIFORNIA SUGAR PINE

MATERIAL LIST

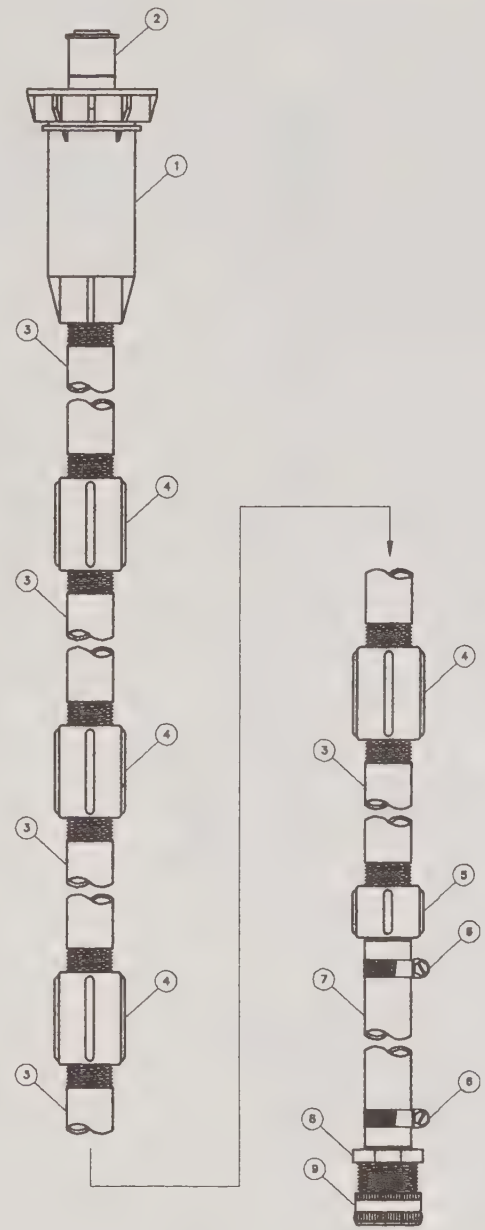
NO	PART NAME	REQD	MATERIAL–DESCRIPTION	SHEET
1	SPRAYHEAD	1	RAINBIRD MODEL 1800 OR EQ.	
2	NOZZLE	1	RAINBIRD MODEL 8F-FLT OR EQ.	
3	PIPE	5	1/2 SCHEDULE 80 PVC, 61 CM (2 FT) LONG.	
4	COUPLING	4	1/2 SCHEDULE 40 PVC.	
5	ADAPTER	1	1/2 FEMALE NPT X 3/4 MALE GHT, BRASS.	
6	QUICK CONNECTOR	1	3/4 GHT, BRASS	
7	WATERLINE	2	LIGHTWEIGHT FIREHOSE, NFES #1016, 3/4 GHT, 5/8 X 15M (50 FT) LONG, SYNTHETIC.	
8	CAP	1	3/4 FEMALE GHT, BRASS.	
9	STRAPS	AR	2.5 CM (1 IN.) NYLON STRAPS WITH NON-SLIP NYLON BUCKLES.	

NOTE: APPLY TEFLON TAPE ON THREADS.

TOLERANCES: FRACTIONS +/- ___ DECIMALS +/- ___ ANGLES +/- ___	DATE	REVISION	BY
DRAWN W.A.G./WYATT	U. S. DEPT. OF AGRICULTURE FOREST SERVICE TECHNOLOGY & DEVELOPMENT CENTER MISSOULA, MONTANA		
DESIGNED D. HERZBERG	TITLE SINGLE TREE SPRAY SYSTEM CONFIGURATION NO. 1		
CHECKED D. HERZBERG			
APPROVED D. RISING	923-1		
SCALE FULL			
DATE JUN - 95	SHEET 1 OF 3	MTDC- 923	



ASSEMBLY – CALIFORNIA SUGAR PINE



MATERIAL LIST

NO	PART NAME	REQ'D	MATERIAL–DESCRIPTION	SHEET
1	SPRAYHEAD	1	RAINBIRD MODEL 1800 OR EQ.	
2	NOZZLE	1	RAINBIRD MODEL 8F-FLT OR EQ.	
3	PIPE	8	1/2 SCHEDULE 80 PVC, 61 CM (2 FT) LONG.	
4	COUPLING	4	1/2 SCHEDULE 40 PVC.	
5	ADAPTER	1	1/2 INSERT X 3/4 MALE NPT, PVC.	
6	HOSE CLAMP	2	1/2 WORM DRIVE HOSE CLAMP, STN. STEEL.	
7	WATERLINE	1	1/2, 125 PSI, ASTM-D-2239 POLYETHYLENE PIPE.	
8	ADAPTER	1	1/2 INSERT X 3/4 MALE GHT, PVC.	
9	CAP	1	3/4 FEMALE GHT, BRASS.	
10	STRAPS	AR	2.5 CM (1 IN.) NYLON STRAPS WITH NON-SLIP NYLON BUCKLES.	

NOTE: APPLY TEFLON TAPE ON THREADS.

TOLERANCES:
FRACTIONS +/- ___
DECIMALS +/- ___
ANGLES +/- ___

DRAWN	W.A.G./WYATT
DESIGNED	D. HERZBERG
CHECKED	D. HERZBERG
APPROVED	D. RISING
SCALE	FULL
DATE	JUN – 95

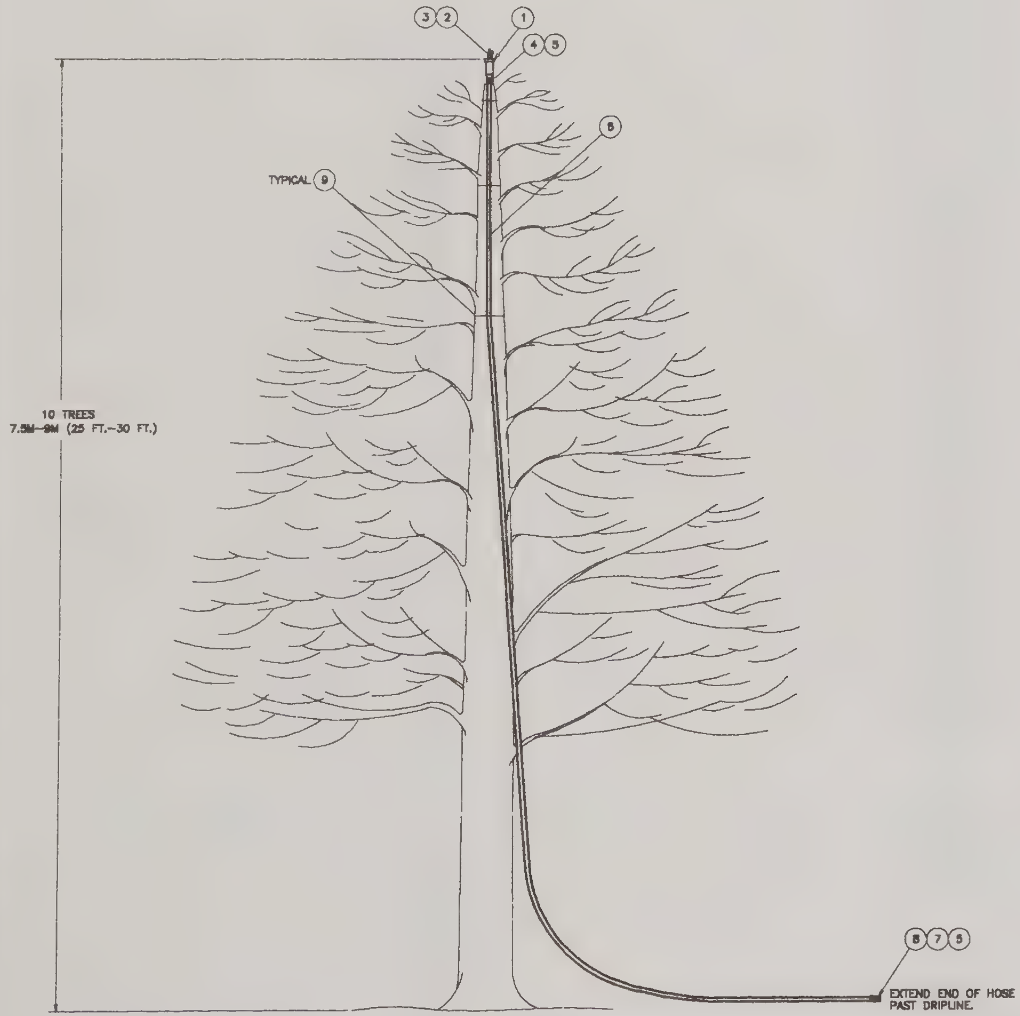
DATE	REVISION	BY

U. S. DEPT. OF AGRICULTURE
FOREST SERVICE
TECHNOLOGY & DEVELOPMENT CENTER
MISSOULA, MONTANA

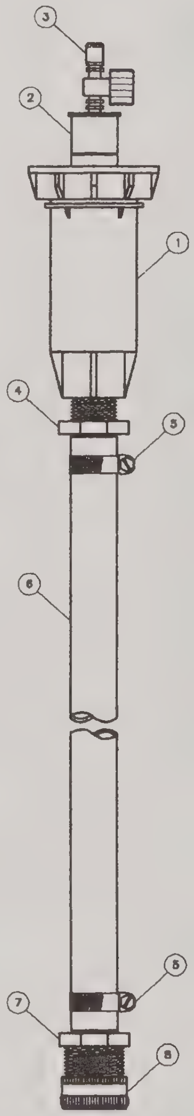
TITLE
SINGLE TREE SPRAY SYSTEM
CONFIGURATION NO. 2

923-2

SHEET 2 OF 3 MTDC– 923



WESTERN WHITE PINE SEED ORCHARD
COEUR D'ALENE NURSERY CONFIGURATION



MATERIAL LIST

NO	PART NAME	REQD	MATERIAL–DESCRIPTION	SHEET
1	SPRAYHEAD	1	RAINBIRD MODEL 1800 OR EQ.	
2	ADAPTER	1	RAINBIRD MODEL XBA-1800 10-32 EMISSION OR EQ.	
3	NOZZLE	1	RAINBIRD MODEL XS-360 ADJ. RADIUS SPRAY OR EQ.	
4	ADAPTER	1	1/2 INSERT X 3/4 MALE NPT.	
5	HOSE CLAMP	2	1/2 WORM DRIVE HOSE CLAMP, STN. STEEL.	
6	WATERLINE	1	1/2, 125 PSI, ASTM-D-2239 POLYETHYLENE PIPE.	
7	ADAPTER	1	1/2 INSERT X 3/4 MALE GHT.	
8	CAP	1	BRASS CAP, 3/4 FEMALE GHT.	
9	STRAPS	AR	NYLON CORD.	

NOTE: APPLY TEFLON TAPE ON THREADS.

TOLERANCES: FRACTIONS +/- ___ DECIMALS +/- ___ ANGLES +/- ___	DATE / REVISION / BY
	U. S. DEPT. OF AGRICULTURE FOREST SERVICE TECHNOLOGY & DEVELOPMENT CENTER MISSOULA, MONTANA
DRAWN W.A.G./WYATT	TITLE
DESIGNED D. HERZBERG	SINGLE TREE SPRAY SYSTEM
CHECKED D. HERZBERG	CONFIGURATION NO. 3
APPROVED D. RISING	923-3
SCALE FULL	
DATE JUN - 95	SHEET 3 OF 3 — MTDC– 923

Appendix B—Rain Bird's Specifications for Sprinklers Used in Single Tree Spray Systems

1800 SERIES
PLASTIC MPR NOZZLES

Operating Range

Precipitation Rate:
0.78 to 5.15 inches per hour
Spacing: 5 to 15 feet
Pressure: 15 to 30 psi

Water Management Features

- Matched precipitation rates across sets and across patterns
- 1800 Series screens maintain precise radius adjustment – shipped with nozzles

*Note: 8 Series on 6'' and 12'' pop-ups; all others tested on 4'' for MPR performance.

Features

- For use on all 1800 Series sprinklers and the PA-8S and PA-8S-PRS shrub adapters
- Adjustable flow and radius
- Stainless steel adjustment screw

8 Series* Plastic — **Flat 5° Trajectory**

NOZZLE	PSI	RADIUS'	GPM	*PRECIP.■	PRECIP.△
8F-FLT	15	7	1.16	2.27	2.63
	20	8	1.30	1.96	2.26
	25	9	1.44	1.72	1.98
	30	10	1.57	1.52	1.75
8H-FLT	15	7	0.58	2.27	2.63
	20	8	0.65	1.96	2.26
	25	9	0.72	1.72	1.98
	30	10	0.79	1.52	1.75
8T-FLT	15	7	0.39	2.27	2.63
	20	8	0.43	1.96	2.26
	25	9	0.48	1.72	1.98
	30	10	0.52	1.52	1.75
8Q-FLT	15	7	0.29	2.27	2.63
	20	8	0.33	1.96	2.26
	25	9	0.36	1.72	1.98
	30	10	0.39	1.52	1.75

*Performance at 12'' above finished grade.

8 Series* Plastic — **Flat 5° Trajectory**

NOZZLE	PSI	RADIUS'	GPM	*PRECIP.■	PRECIP.△
8F-FLT	15	5	1.16	4.46	5.15
	20	6	1.30	3.48	4.02
	25	7	1.44	2.84	3.28
	30	8	1.57	2.37	2.74

SPRAY SPRINKLERS

Rain Bird plastic and brass spray sprinklers are designed to deliver superior performance and long-lasting quality.

Rain Bird provides the most complete, innovative line of sprayheads, nozzles and accessories in the industry. Look through the following pages for the right product to meet your specific water management needs.

Precipitation Rates

Precipitation rates have been calculated for your use. For a given pattern of similar sprinklers, these rates are an indication of the approximate rate at which water is being applied. The average precipitation rate (P_R) is expressed in the units inches/hour. The equations used to calculate the precipitation rates are:

■ **Square Spacing**

$$P_R = \frac{96.3 \times GPM}{S \times S}$$

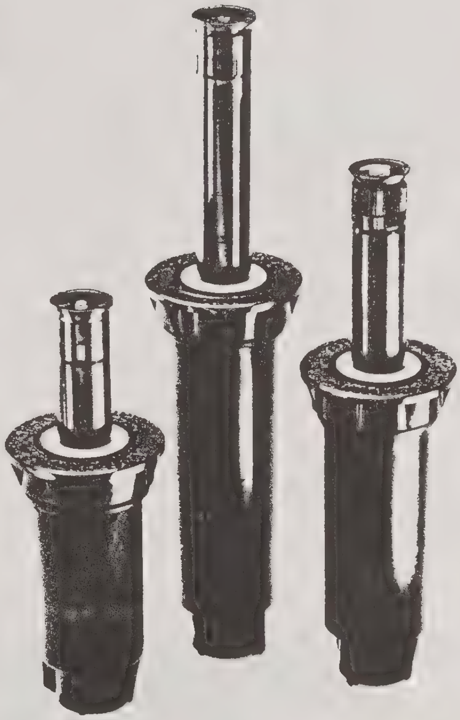
▲ **Triangular Spacing**

$$P_R = \frac{96.3 \times GPM}{S \times L}$$

96.3 = Constant (inches/square foot/hour)
GPM = Gallons per minute applied to area by sprinklers
S = Spacing between sprinklers
L = Spacing between rows (S x .866)

Model/Letter Designations

A:	Model Designation Only
B:	Bubbler or Brass
A-F:	Model Designation Only
FLT:	Flat Spray
LA:	Low Angle
SS:	Stream Spray
SLA:	Low Angle Stream Spray
F:	Full Circle
TQ:	Three Quarter Circle
TT:	Two Third Circle
H:	Half Circle
T:	Third Circle
Q:	Quarter Circle
EST:	End Strip
CST:	Center Strip
SST:	Side Strip
SQ:	Square
E:	One Eighth
PCS:	Pressure Compensating Screen
PRS:	Pressure Regulating Stem
SAM:	Seal-A-Matic™



Multi-function co-molded wiper seal (shown in white) assures positive pop-up and pop-down. The wiper seal begins operation at a low 8 psi to end flow-by problems.

1802/1803/1804/1806/1812

Pop-up Spray Sprinklers

Operating Range

Precipitation Rate:
.34 to 6.18 inches per hour
Spacing: 5 to 24 feet
Pressure: 15 to 70 psi

Features

- Precipitation rates matched across sets
- Precipitation rates matched across patterns
- Pop-Up Heights: 2″–1802, 3″–1803, 4″–1804, 6″–1806 and 12″–1812
- Ratcheting on all models
- Exclusive multi-function wiper seal
- Plastic and stainless steel materials
- Seamless, molded construction doubles burst strength
- Extra strength, stainless steel retract spring
- Fully adjustable flow
- Under-the-nozzle filter screen maintains precise radius adjustment (shipped with nozzle)
- Easy to service from the top of sprinkler
- Full flow inlet opening
- Side or bottom inlet on 1806 and 1812 only
- Shipped with 1800 Pop-Top™ flush plug installed

Dimensions

- ½″ female threaded inlets
- Body height: 1802–4″; 1803–4⅞″; 1804–6″; 1806–9⅜″; 1812–16″
- Exposed diameter–2⅕″
- Flow-by: 0 GPM at 8 psi or greater, .05 GPM otherwise

How To Specify:

1804-15H

MODEL — NOZZLE SERIES/PATTERN

This specifies an 1800 Series sprayhead with 4″ pop-up height; 15 series plastic nozzle; with half circle pattern – (see nozzle performance charts pages 9-11).

RAIN BIRD
PREFERRED BY PROFESSIONALS WORLDWIDE ®

Adjustable Micro-spray Emission Devices

XERI-SPRAYS™

XS-360, XS-180, XS-090

Features

- Adjustable flow/radius by turning integral ball valve
- Uniform distribution pattern provides excellent uniformity
- 10-32 self-tapping threads fit into ½" x 10-32 adapter (10-32A): 1800 Xeri-Bubbler adapter (XBA-1800): and polyflex riser (PFR-12)
- Ideal for mass plantings, ground cover and annual flower beds

Operating Range

- Flow: 0 to 31 GPH (0 to 120.1 l/h)
- Pressure: 10 to 30 psi (0.75 to 2 Bars)
- Radius: 0 to 13.4 feet (0 to 4,1 m) full circle; 0 to 10.6 feet (0 to 3,2 m) quarter and half circle

Models

Model	Pattern	Type
XS-360	Full	Stream
XS-180	Half	Spray
XS-090	Quarter	Spray

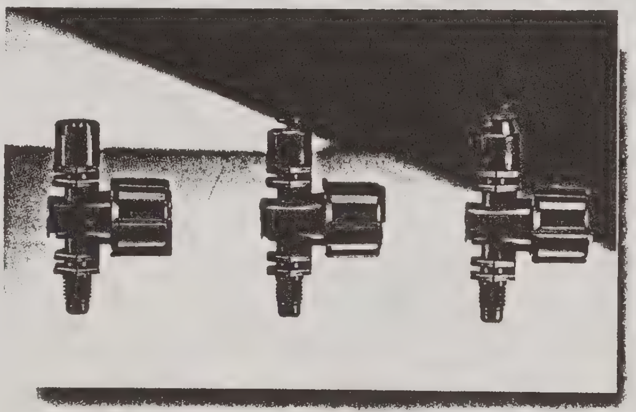
Xeri-Sprays
Performance

Pressure P.S.I.	Flow GPH	XS-360 Radius of Throw ft	XS-180 Radius of Throw ft	XS-090 Radius of Throw ft
10	0 - 16.7	0 - 9.2	0 - 6.7	0 - 6.4
15	0 - 21.0	0 - 11.3	0 - 8.1	0 - 8.1
20	0 - 24.5	0 - 12.9	0 - 9.5	0 - 9.4
25	0 - 28.0	0 - 13.2	0 - 10.1	0 - 9.8
30	0 - 31.0	0 - 13.4	0 - 10.6	0 - 10.3

Xeri-Sprays
Performance

METRIC

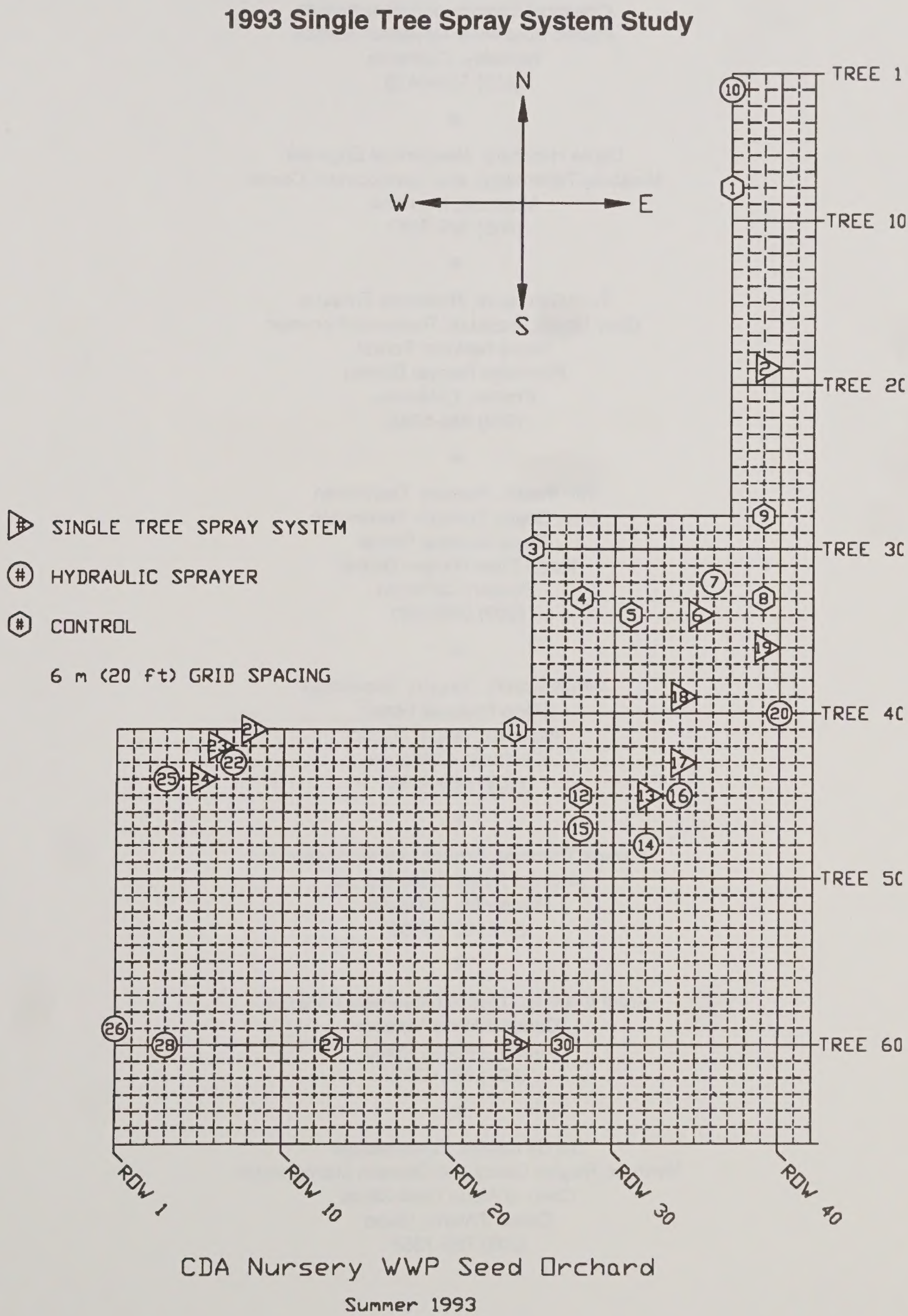
Pressure Bars	Flow l/h	XS-360 Radius of Throw m	XS-180 Radius of Throw m	XS-090 Radius of Throw m
0,75	0 - 60,6	0 - 2,8	0 - 2,0	0 - 1,9
1	0 - 81,4	0 - 3,5	0 - 2,5	0 - 2,5
1,5	0 - 94,9	0 - 3,9	0 - 2,9	0 - 2,8
1,75	0 - 108.5	0 - 4,0	0 - 3.1	0 - 3,0
2	0 - 120,1	0 - 4,1	0 - 3.2	0 - 3,1



XS-360 XS-180 XS-90

XERIGATION PRODUCTS

Appendix C—Map of Study Trees at the Coeur d'Alene Nursery Seed Orchard



Appendix D—Persons Involved With the Single Tree Spray Study

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